1 INTRODUCTION

". . . without a moment's warning, a subterranean roar was heard, buildings shook from garret to cellar, the fearful noises growing louder and louder, building's swaying to and fro like trees in a storm, and then came the crash of tumbling houses, and simultaneously mingling with those notes of horror, came the shrieks and wailings of frightened women and children."

– newspaper report, Charleston, South Carolina, September 1, 1886

THE SCIENCE OF EARTHQUAKES

Earthquakes have long been feared as one of nature's most terrifying phenomena. Early in human history, the sudden shaking of the earth and the death and destruction that resulted were seen as mysterious and uncontrollable. Often, the upheaval of the ground was seen as an act of retribution by a supernatural power. The Japanese, for example, believed that earthquakes were caused by the stirring of a huge catfish – *Namazu* – who lived in the ocean depths. Nineteenth century Japanese prints show *Namazu* alternatively being attacked by irate citizens whose homes he had destroyed or being wined and dined by building contractors whom he had enriched.

NAMAZU, THE GIANT CATFISH

The theory of plate tectonics proposed in 1969 has removed the mystery by explaining the origin of earthquakes and showing that they must be accepted as a natural environmental process, one of the periodic adjustments that the earth makes in its evolution. This scientific explanation, however, has not lessened the terrifying nature of the earthquake experience. Indeed, in some respects, it has increased it for now, when we tend to expect to control nature's forces to a degree inconceivable only a century or so ago, earthquakes continue to remind us that nature still can strike without warning and, after only a few seconds, leave damage and casualties in its wake. This uncertainty, lack of warning, and instant threat to life contributes to our fundamental fear of earthquakes. Beyond the threat to life is the threat of the destruction of public and private property. Jobs, services, and business revenues can disappear instantly and, for many, homelessness can suddenly be very real.

The aftermath of a great earthquake endures for years or even decades: six years after the Loma Prieta earthquake centered in Santa Cruz County, California, the central retail area of Santa Cruz is still only partially reconstructed and San Francisco traffic remains hampered by freeways still being replaced and repaired.

Although earthquakes cannot be prevented, modern science and engineering provide tools that can be used to reduce their effects. Science can now identify, with considerable accuracy, where earthquakes are likely to occur and what forces they will generate while engineering permits the design and construction of structures that will survive these forces.

Seismic safety, however, is a complex issue that involves life safety, community values, and a relatively uncommon hazard. Since scientific seismic hazard information understandable to those who are not scientists often is not available, a community's public officials, building professionals, and citizenry may not even realize that a seismic hazard exists, let alone understand the risk that it poses.

Several misconceptions contribute to this lack of appreciation for seismic risk in many U.S. communities. Consider the following true or false questions to determine your level of earthquake awareness:

- **Since most Americans have not experienced a large, damaging earthquake, it is unlikely that they will during their lifetime.**

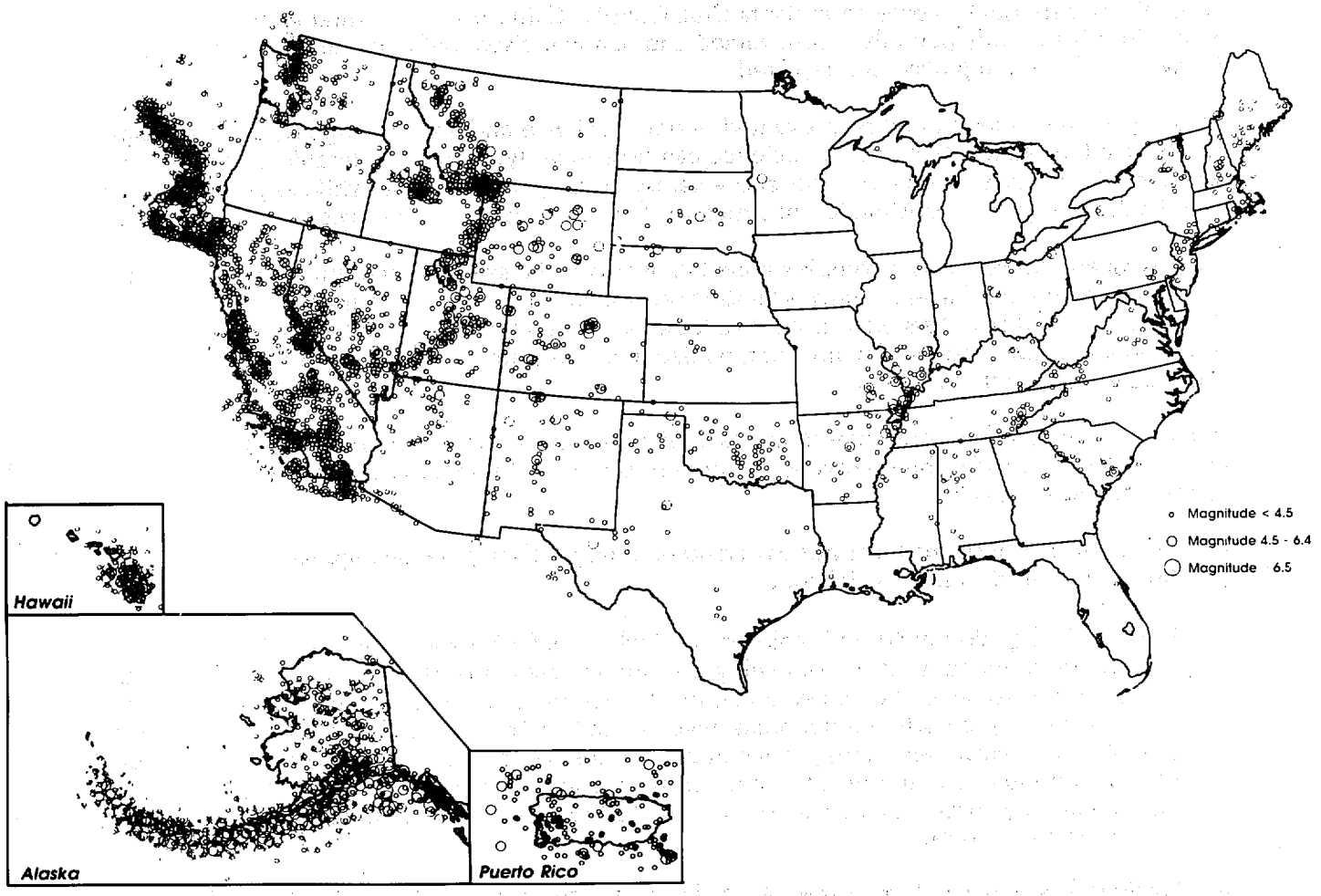
  FALSE! Earthquakes occur in "geologic time" which is far "slower" than that which we usually use to judge whether something is of immediate concern to us. Records show that some seismic zones in the United States experience moderate to major earthquakes about every 50 to 70 years while other areas have "repeat" or "recurrence" intervals of about 200 to 400 years. However, these probabilities or "odds" are simply best estimates, and one or several earthquakes could occur in a much shorter-than-average period. The rule of thumb cited by some seismic experts is: "The further you are from the last one, the closer you are to the next one."

- **Earthquakes occur only in a few places in the United States, primarily California and Alaska.**

  FALSE! As indicated in the map on the next page, more than 40 of the 50 states as well as many U.S. territories and possessions are at some risk from earthquakes. In fact, the greatest U.S. earthquakes occurred not on the West Coast, but in the East and Midwest.

- **Local building codes and regulations in areas of seismic risk generally include seismic safety provisions.**

  FALSE! The building codes in many communities at risk from earthquakes include no seismic provisions.



Seismicity of the United States: 1899 - 1990 (from the U.S. Geological Survey National Earthquake Information Center, prepared by Susan K. Goter).

- **If a community's building regulations include seismic provisions, there will be no damage to the buildings designed under those regulations.**

  FALSE! As with building codes in general, the principal purpose of seismic code provisions is to put forth minimum standards to ensure public safety, health, and welfare insofar as they are affected by building design and construction. Because of the many variables concerning the nature, extent and frequency of earthquake forces, measures essential to ensure total safety from earthquakes would be prohibitively expensive. Thus, seismic code provisions usually reflect some degree of compromise. Seismic code provisions generally are formulated to ensure that structures resist minor earthquakes without damage, resist moderate earthquakes without structural damage but suffer some nonstructural damage, and resist major earthquakes without collapse but with some structural as well as nonstructural damage. This approach is based on the study of many earthquakes where it has been shown that structural collapse is the overwhelming cause of life loss and serious injury. It is important to understand, however, that damage may

occur in even a very well designed building if it is subjected to the effects of a violent or severe earthquake.

- **Requiring seismic design and construction for new buildings will not really lessen a community's risk because of all the existing buildings that were not built to resist earthquakes.**

  FALSE! With respect to the seismic hazard, there is no doubt that those buildings not designed to resist earthquakes are at some risk. In areas where earthquakes occur often and seismic design for new buildings has been required for many years (for example, in California), efforts to rehabilitate existing buildings to resist earthquakes are being given considerable attention even though they are expensive. In the eastern and central states, however, where seismic requirements for new buildings have been the exception rather than the rule, it is most reasonable to start by protecting new construction. After addressing new construction, a community should at least evaluate its existing building inventory to determine whether certain important facilities that are expected to remain in service for a long period of time (for example, schools and hospitals) should be rehabilitated to resist earthquakes.

No matter how well or how poorly you scored on this quiz, once you and other concerned individuals in your community seriously consider the social, economic, and legal implications of the earthquake risk to buildings and to those who occupy them, you will actively support efforts to improve the seismic resistance of these facilities.

NEED FOR LOCAL SEISMIC HAZARD ASSESSMENT

Those responsible for or concerned about a community's buildings first need to research the local seismic situation to determine the community's seismic hazard. Once this is done, an individual or a community as a whole will have a rational basis for deciding how much seismic risk to accept and the degree to which the risk should be lessened. The adoption of building code regulations based on up-to-date seismic safety design provisions like the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings* is generally considered to be one significant way of lessening the risk to life by requiring that new buildings be designed and constructed in a manner that will prevent their structural collapse during an earthquake.

IMPLICATIONS OF SEISMIC DESIGN

The use of seismic design provisions can affect a building owner or a community in various ways and to varying degrees. Among the major factors to be considered are the following:

- Buildings designed and constructed in accordance with up-to-date seismic provisions can be expected to reduce life loss, injuries, and property damage when an earthquake occurs. For an individual building owner, this should reduce the cost of repairs and minimize the amount of time that the building cannot be used. For a community, this should reduce the costs of emergency response and recovery, keep essential facilities operational, and lower the cost of replacing public buildings.

- The possibility of costly litigation concerning liability for earthquake effects most likely would be reduced for all those involved in the building process.

- Requiring seismic design and construction of new buildings may increase costs but far less than many people think. From a community's perspective, these increased costs could result in a reduced supply of housing and of industrial and commercial facilities, reduced availability of housing or other facilities to a particular income segment of the market, and/or a loss of business development (and the accompanying jobs and tax revenues) to neighboring jurisdictions that do not enforce seismic regulations.

The degree to which these effects will be felt depends on several factors including the nature of the seismic hazard, the degree of seismic risk that a building owner or a community deems to be acceptable, and the extent to which something has already been done to mitigate the risk. A variety of community members with different roles and varying interests will play a part in assessing the significance of these effects and the decision each makes will reflect his or her view of what is important.

CONTENTS OF THIS BOOK

The remainder of this book is structured to provide both concerned individuals and community decision-makers with information they can use in assessing their situation and in making more informed and reasoned decisions. It is intended for a broad audience composed of both those who have little specific knowledge about building regulation, seismic phenomena, design, and engineering and for those who are somewhat familiar with these concepts. Specifically, the remainder of this book provides information on:

- Who and what is at risk in Chapter 2,
- What earthquakes do to buildings in Chapter 3,
- Seismic codes and the importance of the *NEHRP Recommended Provisions* in Chapter 4,
- How to stimulate community action in Chapter 5, and
- Some factors to be considered in deciding whether and how to take action to mitigate the risk from earthquakes in Chapter 6.

Appendices provide readers with additional helpful information:

- Appendix A defines terms and concepts frequently used in discussions of seismicity and seismic design and construction;
- Appendix B explains the U.S. building regulatory system;
- Appendix C explains the nature of earthquake ground motion and how buildings can be designed and constructed to resist earthquakes;
- Appendix D presents an overview of U.S. seismicity; and
- Appendix E lists organizations, publications, and electronic resources that offer more specific information and assistance.

Readers not deeply involved with the building process are encouraged to read Chapters 2 through 6 and then to pursue those topics covered in the appendices that are of special interest to them. Although Appendix C presents information that is relatively technical, the

nontechnical reader is urged to at least scan this appendix since it features a number of illustrations that may help to clarify important aspects of earthquake effects on buildings and the importance of seismic design.